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FINAL TECHNICAL REPORT
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Earthquake Hazard Research in the Pacific Northwest using Washington Regional Seismograph Network Data

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NON-TECHNICAL ABSTRACT

Research under this grant used data from the Pacific Northwest Seismograph Network (PNSN) to study several aspects of earthquake hazards in the Pacific Northwest, including of two significant earthquake sequences, March 25, 1993 Scotts Mills, Oregon M 5.7 earthquake and the January 29, 1995 Robinson Point M 5.0 Puget lowland earthquake. Other research results under this grant include an investigation of the crustal structure beneath the Cascades, development of a method to accurately estimate earthquake moment from standard network data, and preliminary work on seismic wave velocity structure in the Puget Basin.

TECHNICAL ABSTRACT

A. The March 25, 1993 Scotts Mills, Oregon earthquake sequence. We have carried out a detailed study of aftershocks and focal mechanisms of the March 25, 1993 Scotts Mills magnitude 5.7 crustal earthquake. The oblique thrust fault causing this earthquake strikes NW and is consistent with other NW striking faults in NW Oregon. Earthquakes as large as magnitude 6 present a hazard to the region. We have also found that ground motion variations are strongly affected by local geology in the vicinity of Scotts Mills.

B. Source Scaling for Regional Earthquakes We have completed work on the calibration of source moment scaling and station calibration for the Pacific Northwest Seismograph Network (PNSN). This research makes it possible to perform moment estimates more accurately using short period vertical component stations of the network.

C. The January 29, 1995 Robinson Point Puget lowland earthquake. A magnitude 5.0 earthquake occurred on 29 January, 1995 in the central Puget lowland at a depth of about 20 km. This earthquake was well recorded and located in the vicinity of the Seattle fault. We have analyzed the source characteristics of this event using broadband and short-period instrumental data. The fault slip producing this event is consistent with the deeper projections of the Seattle fault and it is possible that the earthquake represents tectonic deformation related to the Seattle fault system.

D. A cross-Cascades refraction profile using earthquake sources. We have completed earlier work on a cross-Cascade deep structure modeling, with results published in JGR. This research has revealed a deep crustal root of the Cascades which we interpret to be of mafic composition. The root is interpreted to be the result of crustal underplating.

E. Investigations of 3-D structure in the Puget lowland region. Under this research, we initiated efforts to obtain higher resolution P-wave velocity structure in the Puget Sound basin using earthquakes and explosions recorded on the PNSN. Toward this end, a tomographic inversion method is being implemented in which finite difference travel-time calculation is performed.

RESULTS

A. Scotts Mills Earthquake Sequence

A magnitude 5.7 crustal earthquake occurred on March 25, 1993 near the town of Scotts Mills, Oregon. This earthquake was centered in a sparsely populated region near the east side of the Willamette Valley, but was nevertheless somewhat damaging in Salem, Oregon. The mainshock was well recorded with the PNSN, and a significant aftershock sequence was well recorded on portable stations deployed following the mainshock.

We analyzed a selected subset of 50 well recorded aftershocks in detail, computing high quality locations and first-motion focal mechanisms for these events. We conclude that the orientation of mainshock mechanism taken together with the aftershock distribution indicates that this event occurred as an oblique thrust on a northwest trending mid-crustal fault [Thomas, et al., 1996]. We tentatively associated this fault with the NW striking Mt. Angel fault which was studied most recently by Werner et al. [1992] in the vicinity of the Scotts Mills epicenters. The existence of a significant crustal fault in this region that has surface expression and can generate a M 5.7 earthquake at a depth of 15 km suggests that the Mt. Angel fault zone could possibly generate significantly larger earthquakes, in the magnitude 6 or greater range.

We are are preparing final revisions of manuscript describing the analysis of ground motion variations recorded in the Scotts Mills region during the aftershock deployment. In this work, we found significant relative site amplification effects, which we attribute to near-surface variations in geology.

B. Source Scaling for Regional Earthquakes

Accurate magnitude and moment estimation is an important aspect of regional network operation. Magnitudes and moments are fundamental characterizations of earthquake that are used in many other types of analysis. For example, fault slip rates and cumulative slip estimates may be made from moment estimates.

To improve our ability to estimate moments using regional network data (specifically, the PNSN data) we explore the use of scattered coda-wave amplitudes using the single scattering amplitude model of Aki and Chouet [1975]. This research led to a practical method which can be automated and incorporated into routine network data analysis. The method is described in Dewberry and Crosson [1995].

C. Robinson Point Earthquake

On January 29, 1995 an unusual magnitude 5.0 mid-crustal earthquake occurred in the southern Puget Sound lowland, between Seattle and Tacoma. The hypocenter of this event was located at about 20 km depth, and only a few sporadic aftershocks followed the mainshock. Although the event was widely felt in the Puget lowland, it was only slightly damaging as a result of its significant depth and location. P-wave first motions from the PNSN show that the mainshock was dominantly a thrust event with nearly east-west striking slip planes.

An empirical Green's function analysis using regional broadband stations indicates that this was a high stress-drop event (430 bars estimated [Dewberry and Crosson, 1996]). A small source region, consistent with the impulsive nature of the source, is also consistent with a tight pattern of epicenters for the few aftershocks that could be accurately located. Comparison with other regional earthquakes of comparable size indicates that earthquakes with hypocenters at depths greater than about 18 km in western Washington (and probably western Oregon) have anomalous aftershock sequences, with few, sporadic aftershocks. Although the reason for this behavior is not clear, it likely reflects temperature or compositional variation with depth.

The hypocenters of the Robinson Point sequence lie about 25 km south of the surface expression of the Seattle fault, an EW striking blind thrust extending across the center of the Puget Lowland. It is possible that the mainshock occurred on a basal extension of the Seattle fault, although uncertainty of the configuration of this fault at depth makes this possibility conjectural. If so, it would be the first direct seismological observation that the Seattle fault is active (although there is paleoseismic evidence of activity; e.g., Bucknam et al. [1992]). Further analysis of this earthquake may provide important insight on this possibility.

D. Cross-Cascade Profile

We have completed work on interpreting a cross-Cascades seismic refraction profile using earthquakes as sources rather than more conventional explosions [Schultz and Crosson, 1996]. In this work, we constructed a profile extending from the vicinity of Hood Canal in western Washington, across the Cascade Range to the vicinity of Walla Walla in southeastern Washington. We chose earthquakes and PNSN seismograph stations lying near the profile, so that a 2-D analysis could be carried out.

The most significant finding of this research is the discovery of seismic evidence for a crustal "root" beneath the Cascade Range. In the depth range between 35 km and 47 km, there is a distinct crustal root that approximately mirrors the topographic profile of the Cascade Range. This root is interpreted as the result of localized magmatic underplating resulting from the release of volatiles in the process of dewatering of the Juan de Fuca slab during subduction. Ultimately, the mass redistribution resulting from underplating produces uplift as a result of isostatic readjustment. Geologic evidence suggest that this process has been enhanced in the past 5-7 m.y., bringing the Cascades to their present topographic prominence. Gravity data are generally consistent with isostatic equilibrium in the Cascade Range and support the seismic model. Our results are the first clear indication of a crustal root beneath the Cascades, and strongly indicate the general nature of late Cenozoic mountain building for the Cascades.

This research also demonstrates the utility of using regional seismograph network data for interpreting structure. When station and earthquake distributions permit, high resolution structure information may be obtained using natural sources.

E. 3-D Structure in the Puget Lowland

The Puget lowland produces the most intense non-localized distribution of small earthquakes in the Pacific Northwest. The recent attention focused on the Seattle fault [e.g., Bucknam et al., 1992] and the Seattle basin [Johnson et al., 1994], have made it clear that 1-D seismic structure may not be adequate for the location of crustal earthquakes in the Puget lowland, and also that earthquakes such as the Robinson Point event (see above) may possibly be related to the Seattle fault. To gain further insight into the relationship between small earthquakes and structure, we need (a) improved regional 3-D velocity structure models, and (b) to be able to use 3-D structure models effectively in locating and studying small and moderate earthquakes.

We have refined the basic finite difference method of Nelson and Vidale [1990] in order to efficiently locate earthquakes in a general 3-D velocity medium. Our refinements include some changes to the finite difference algorithm itself, and refinements in the way grid search is done to make the process more efficient. In the course of this development, we discovered that many earthquakes in the vicinity of the Seattle fault produce double minima in their residual functions, making depth determination problematic. This problem may be worsened by strong lateral velocity variations which we know exist in the central Puget lowland. We are continuing to investigate this problem to resolve possible ambiguities in depth.

The second major objective is to achieve a practical, usable 3-D velocity structure for the Puget lowland and vicinity. We have developed a grid parameterization which allows flexible modeling of diverse input data, including earthquake and explosion travel times. As a first step in the full joint inversion of velocity and hypocenters, we are constructing a model of the Puget lowland using existing refraction/wide-angle reflection models along profile lines and a previous linear tomographic inversion as constraints. This initial reference model allows us to compare different model interpretation for consistency in regions where they intersect. After evaluation, these models will be used as weighted constraints in the general inversion problem.

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APPENDIX 1

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EARTHQUAKE HAZARD RESEARCH IN THE PACIFIC NORTHWEST USING WASHINGTON REGIONAL SEISMOGRAPH NETWORK DATA

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